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RESEARCH MEMORANDUM

STATIC-THRUST CHARACTERISTICS OF THE
NACA 8.75-(5) (05)-037 DUAL-ROTATION PROPELLER

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**NATIONAL ADVISORY COMMITTEE
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SUMMARY

The static-thrust characteristics of the NACA 8.75-(5)(05)-037 dual-rotation propeller having six and eight blades were obtained on the Langley static test stand in the course of an investigation set up primarily for studying blade vibratory stresses. Force data were obtained for a blade-angle range of 4° to 20° , measured at the 0.75 radial station of the front propeller. The blade angle of the rear propeller, measured at the 0.75 radial station, was set 1° less than the front propeller for most of the tests. The maximum propeller tip Mach number for the tests was 0.89.

Generally, increasing the total solidity of the propeller by increasing the number of blades from six to eight gave a higher value of static-thrust figure of merit for all except the lowest values of power coefficient.

INTRODUCTION

Two advantages of the dual-rotation propeller in combination with the gas-turbine engine - high thrust available at low speeds and the small reaction torque - make the combination an attractive means of propelling some types of vertical take-off aircraft. In order to realize fully these advantages, there is a need for additional data pertaining to the thrust-torque relationship for dual-rotation propellers at static and near-static conditions. The most recent data concerning these conditions are reported in reference 1, and results of several investigations are correlated in reference 2.

The purpose of this paper is to supplement the experimental data on dual-rotation propellers with the results from an investigation on the Langley propeller static test stand of the NACA 8.75-(5)(05)-037 dual-rotation propeller having six and eight blades. This investigation

was initiated as a study of vibratory stress due to blade passage, but was extended to include wake-velocity surveys and measurements of thrust and torque. The vibratory measurements and the wake-velocity surveys are presented in references 3 and 4, respectively.

SYMBOLS

a	speed of sound in air, ft/sec
B	number of blades
b	blade width, ft
$c_{l,d}$	design blade-section lift coefficient
C_P	power coefficient, $\frac{P}{\rho n^3 D^5}$
C_T	thrust coefficient, $\frac{T}{\rho n^2 D^4}$
C_T/C_P	static-thrust figure of merit
D	propeller diameter, ft
h	blade-section maximum thickness, ft
M_t	tip Mach number based on rotational speed of propeller tip, $\frac{\pi n D}{a}$
n	propeller rotational speed, rps
P	power, ft-lb/sec
R	propeller-tip radius, ft
r	radius to a blade element, ft
T	thrust, lb
x	fraction of propeller-tip radius, r/R
β	propeller-blade angle at $0.75R$, deg
$\Delta\beta$	difference in blade angles of front and rear propellers of dual-rotation propeller, $\Delta\beta = \beta_F - \beta_R$, deg

σ solidity, $\frac{Bo}{\pi Dx}$

Subscripts:

F front propeller

R rear propeller

APPARATUS

6,000-Horsepower Propeller Dynamometer

The NACA 6,000-horsepower propeller dynamometer consists of two units that can be operated independently as 3,000-horsepower units or coupled and used as a 6,000-horsepower unit. For the present investigation the units were operated separately with the propellers mounted in between. Figure 1 shows the dynamometer on the Langley propeller static test stand with the eight-blade dual-rotation propeller mounted for testing. A detailed description of the dynamometer is given in reference 5.

Propeller

The propeller blades investigated were designed for an advance ratio of 4.2 at a forward Mach number of 0.80. The blades were made of solid aluminum alloy and were designated NACA 8.75-(5)(05)-037 dual-rotation blades. The first number of the designation gives the propeller diameter in feet and the remaining numbers refer to the blade geometry at the 0.70 radius station. The first number in parenthesis indicates a design lift coefficient of 0.5, and (05) indicates a thickness ratio of 0.05. The final number indicates a solidity σ of 0.037 per blade. NACA 16-series airfoil sections were used for the blades. Figure 2 shows the blade-form curves and developed plan form of the propeller blades. The thickness ratio varied from 0.099 at the 0.286 radial station to 0.037 at the 0.950 radial station. The activity factor per blade was 114.32. As the front and rear propellers have the same design section lift coefficient, the design blade angle and pitch distribution of the rear blades differ slightly from the front blades. (See fig. 2.)

TESTS, REDUCTION OF DATA, AND ACCURACY

Tests

Thrust, torque, and rotational speed were measured at intervals of 100 rpm starting at 600 rpm and increasing to a maximum of 2,200 rpm or to the safe operating stress limits. (See ref. 3.) Force data were obtained for a blade-angle range of 4° to 20° in 4° increments measured at the 0.75 radial station of the front propeller. The blade angle of the rear propeller, measured at the 0.75 radial station, was set 1° less than the front propeller. This difference in blade-angle setting is the amount necessary for the propellers to operate at equal power at design conditions. In addition, at a blade-angle setting of 12° on the front propeller, tests were made with the rear-blade angle set at 12° and 10° , giving a $\Delta\beta$ of 0° and 2° , respectively.

The propeller was tested as a six- and an eight-blade configuration, and the spacing between the front and rear propellers was $0.125D$. The front and rear propellers were run at equal rotational speeds for all tests. Spinners were not used for this investigation.

Data Reduction

The thrust and torque data have been reduced to the usual nondimensional coefficients C_T and C_p . No corrections for wind velocity were considered necessary as no tests were conducted with the wind velocity greater than 2.5 ft/sec.

Accuracy

The static calibration of the thrust and torque measuring systems indicate the following probable errors: front thrust, ± 3.5 pounds; rear thrust, ± 4.3 pounds; front torque, ± 2.3 foot-pounds; rear torque, ± 1.5 foot-pounds. The rotational speed of the dynamometer can be set to $\pm 1/4$ rpm. The wind velocity at the test stand was measured by a sensitive hot-wire anemometer.

RESULTS AND DISCUSSION

Effect of Tip Mach Number

The variation of the static-thrust and power coefficients with tip Mach number for the six-blade propeller is shown in figure 3. There was little effect of tip Mach number for the tip Mach number and blade-angle range of the tests. Figure 4 shows the effect of tip Mach number on the thrust and power coefficients of the eight-blade propeller. With the exception of C_p for the rear propeller, the effects of tip Mach number were the same as for the six-blade propeller. In the excepted case, there was a decrease in C_p with increasing tip Mach number at low values of tip Mach number which is similar to results presented in reference 1. No satisfactory explanation can be given for this decrease in C_p . The variation of total C_T and C_p with tip Mach number is shown in figure 5. As the front and rear propellers were run at equal rotational speed, the total C_T and C_p were obtained by addition of data at equal tip Mach numbers.

The variation of total thrust with tip speed is presented in figure 6. Also shown in figure 6 is the total thrust computed by using the empirical method from reference 2. The computed thrust at the lower blade angles is within 5 percent of the measured thrust, but is about 13 percent low at the higher blade angles.

Effect of Number of Blades

The variation of the static-thrust figure of merit C_T/C_p with power coefficient is shown in figure 7 for both the six- and the eight-blade dual-rotation propellers at tip Mach numbers of 0.40 and 0.60. The curves show that the effect of increasing the solidity by increasing the number of blades from six to eight depends upon the power coefficient at which the propeller is operating. At a fixed value of tip Mach number there is a power coefficient, usually quite low, where the static-thrust figure of merit is equal for six- and eight-blade dual-rotation propellers. At power coefficients higher than this value the eight-blade propeller has the higher value of C_T/C_p , and at power coefficients lower than this value the six-blade propeller has the higher value of C_T/C_p . In general, the eight-blade propeller has the higher value of static-thrust figure of merit for all except the lowest values of power coefficient because of its better power-absorption qualities. At the higher power coefficients more of the blade sections of the eight-blade propeller are operating at angles of attack to produce lift coefficients which are nearer to those for the ratio of maximum lift to drag than are the blade sections of the six-blade propeller when absorbing the same power. Note that the curves

in figure 7 show a maximum value of C_T/C_P for the eight-blade propeller at a power coefficient of only about 0.05.

The curves in figure 7 also show that for a given power coefficient the effect of increasing the tip Mach number from 0.4 to 0.6 for either of the two propellers is to increase the value of C_T/C_P .

Effect of Blade Angle

The variation with blade angle of the static-thrust and power coefficients and the static-thrust figure of merit C_T/C_P of the front and rear propellers is shown in figure 8 at a tip Mach number of 0.60. In figure 8, C_T/C_P for the front propeller is similar to that for a single-rotation propeller (ref. 6), but the angle of attack for the rear-propeller sections is reduced as a result of the slipstream from the front propeller. This reduction in angle of attack results in a shift of the peak value of C_T/C_P to higher blade angles for the rear propeller. This shift is an indication of the effect of the interference velocity experienced by each propeller. It is seen that, compared to the effect of the front propeller on the rear propeller, the effect of the rear propeller on the static-thrust figure of merit of the front propeller is negligible.

For a blade-angle setting of 12° on the front propeller ($\beta_F = 12^\circ$), β_R was set at 12° and 10° and gave a $\Delta\beta$ of 0° and 2° . The result of increasing $\Delta\beta$ was a decrease in C_T and C_P of the rear propeller (fig. 9) while there was little, if any, effect on the thrust and power coefficients of the front propeller. It appears that a $\Delta\beta$ of about -1° would have given equal power for static conditions.

CONCLUDING REMARKS

The static-thrust characteristics of the NACA 8.75-(5)(05)-037 dual-rotation propeller having six and eight blades were investigated on the Langley propeller static test stand and indicate the following results:

1. In general, the eight-blade dual-rotation propeller has a higher value of static-thrust figure of merit than the six-blade dual-rotation propeller for all except the lowest values of power coefficient because of its better power-absorption qualities.

2. For a given power coefficient the effect of increasing the tip Mach number from 0.4 to 0.6 for either the six- or the eight-blade dual-rotation propeller is to increase the value of the static-thrust figure of merit.

3. The effect of the rear propeller on the static-thrust figure of merit of the front propeller is negligible compared with the effect of the front propeller on the rear propeller.

4. The computed total thrust by the empirical method at the lower blade angles was within 5 percent of the measured thrust.

5. It appears that a difference of -1° in blade angles of the front and rear propellers would have given equal power at static conditions.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., March 7, 1956.

REFERENCES

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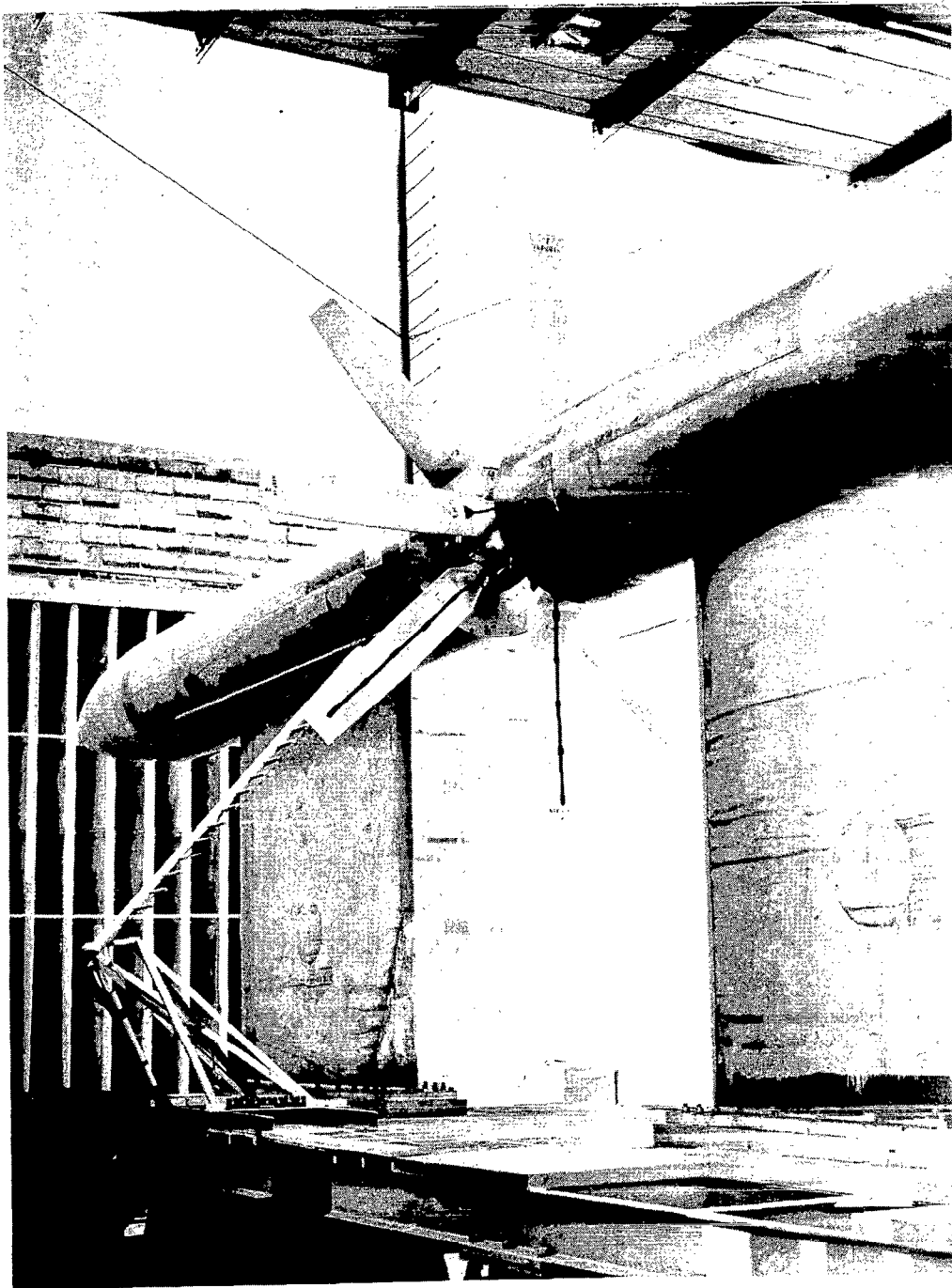


Figure 1.- NACA 6,000-horsepower propeller dynamometer at the Langley static test stand with the NACA 8.75-(5)(05)-037 eight-blade dual-rotation propeller mounted. L-78831

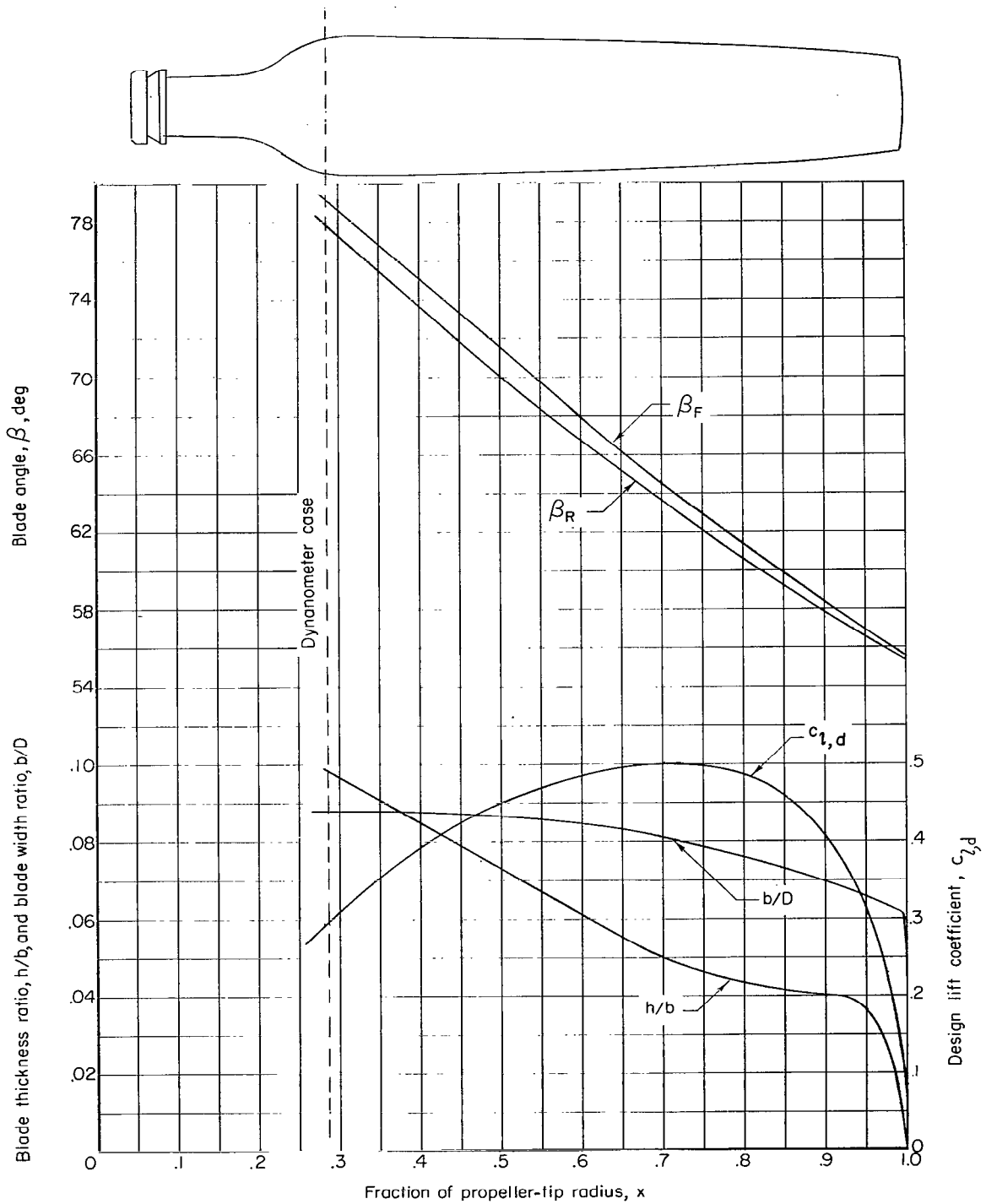


Figure 2.- Blade-form curves for the NACA 8.75-(5)(05)-037 dual-rotation propeller.

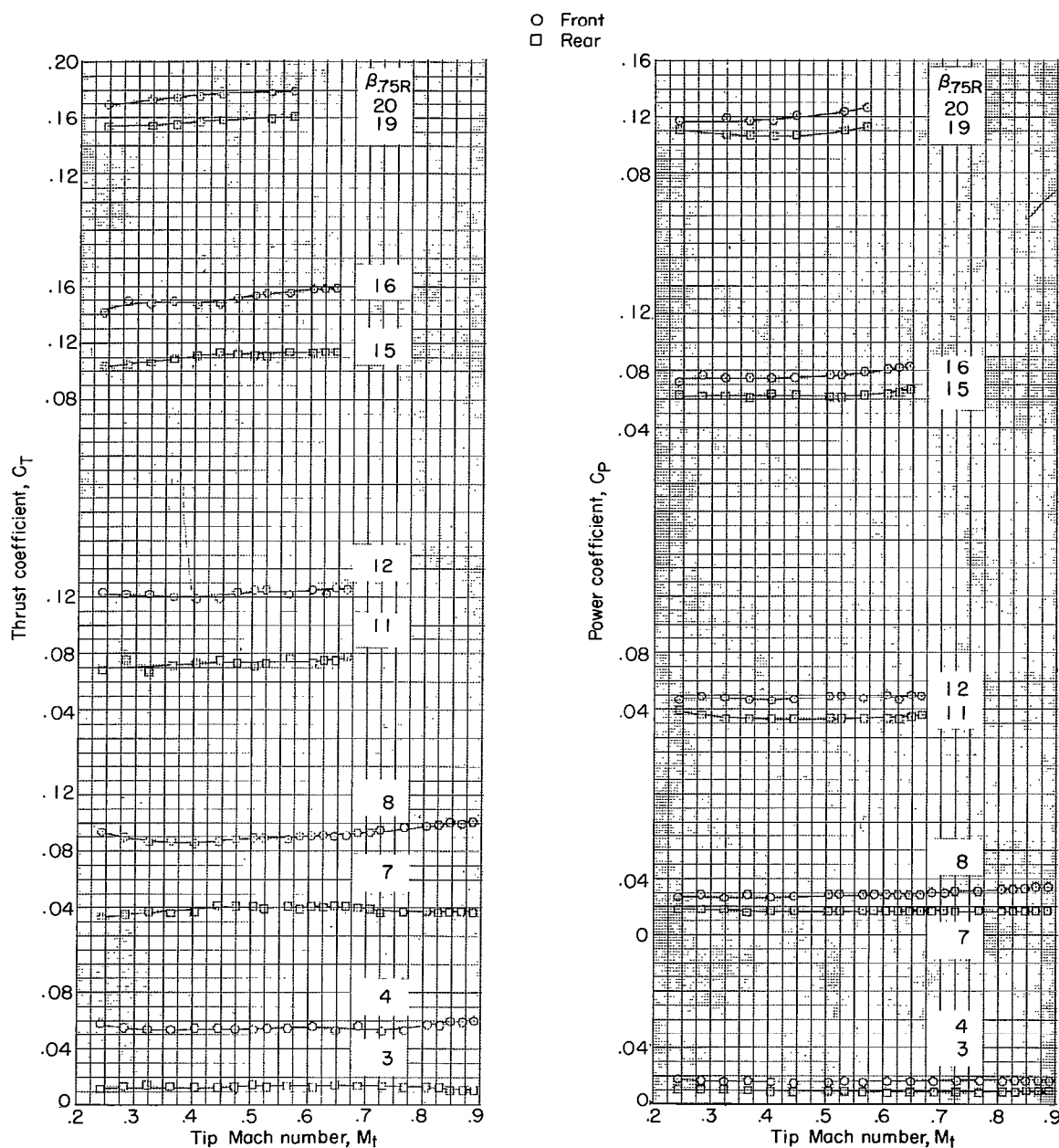


Figure 3.- Variation of static-thrust coefficient C_T and power coefficient C_p with tip Mach number for NACA 8.75-(5)(05)-037 dual-rotation propeller with six blades.

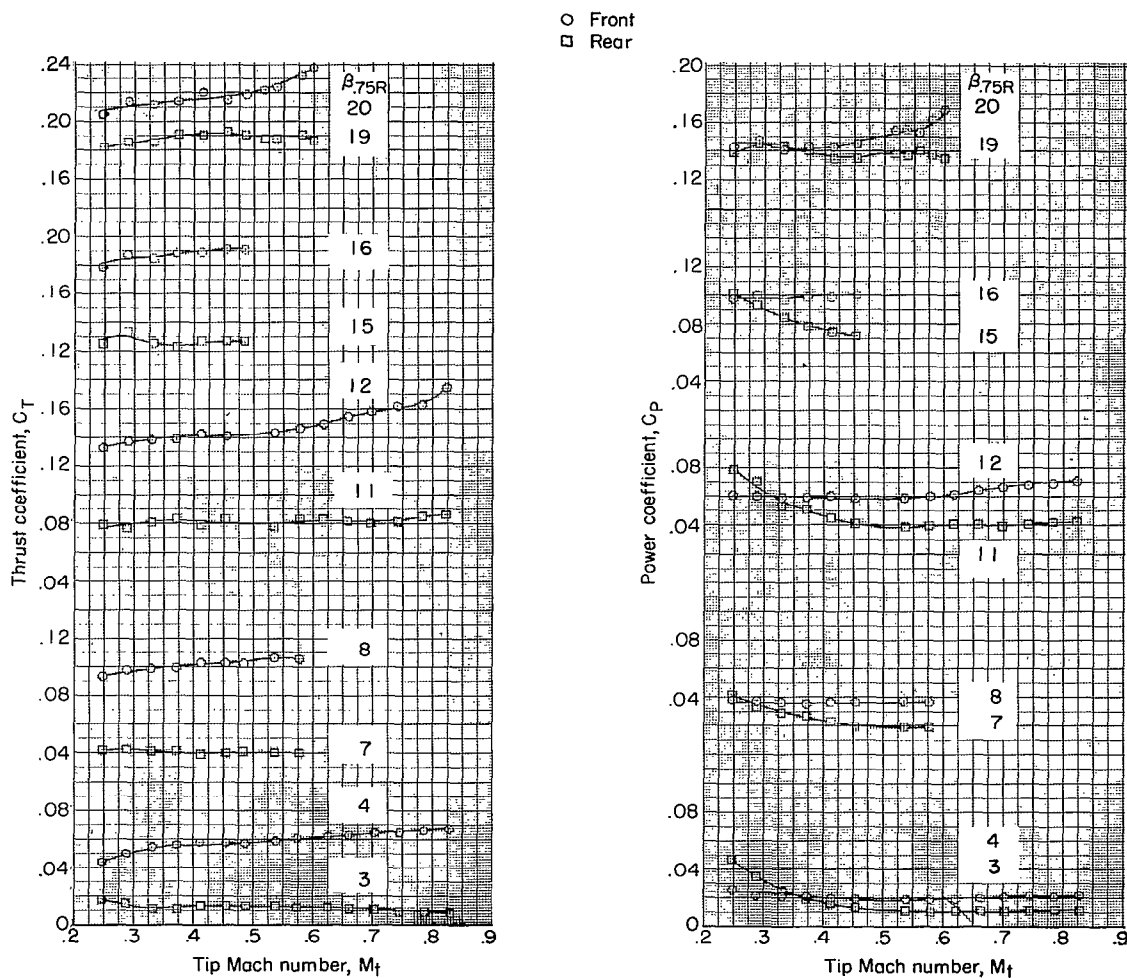


Figure 4.- Variation of static-thrust coefficient C_T and power coefficient C_P with tip Mach number for NACA 8.75-(5)(05)-037 dual-rotation propeller with eight blades.

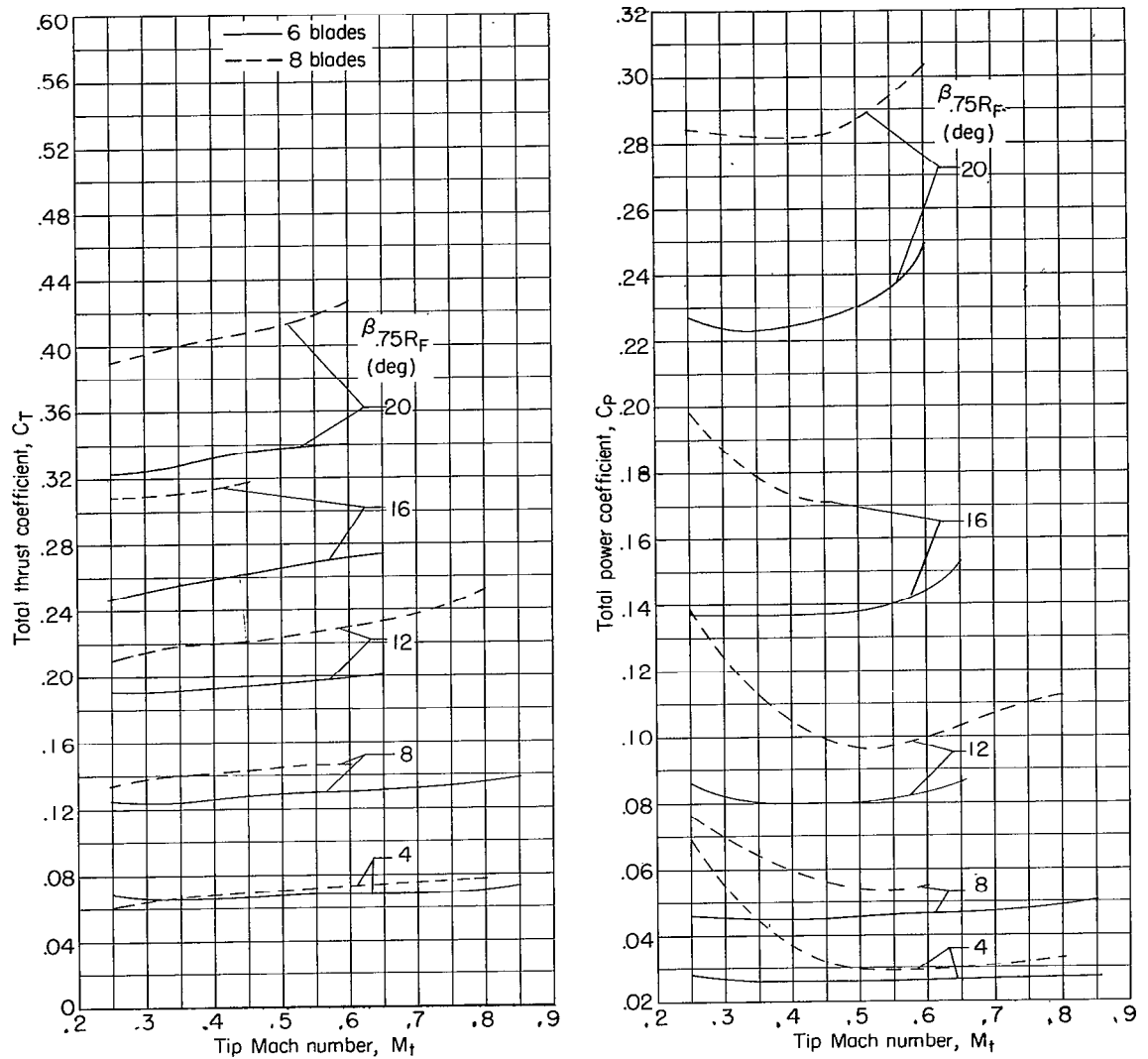


Figure 5.- Variation of total static-thrust coefficient and power coefficient with tip Mach number for NACA 8.75-(5)(05)-037 dual-rotation propeller with six and eight blades.

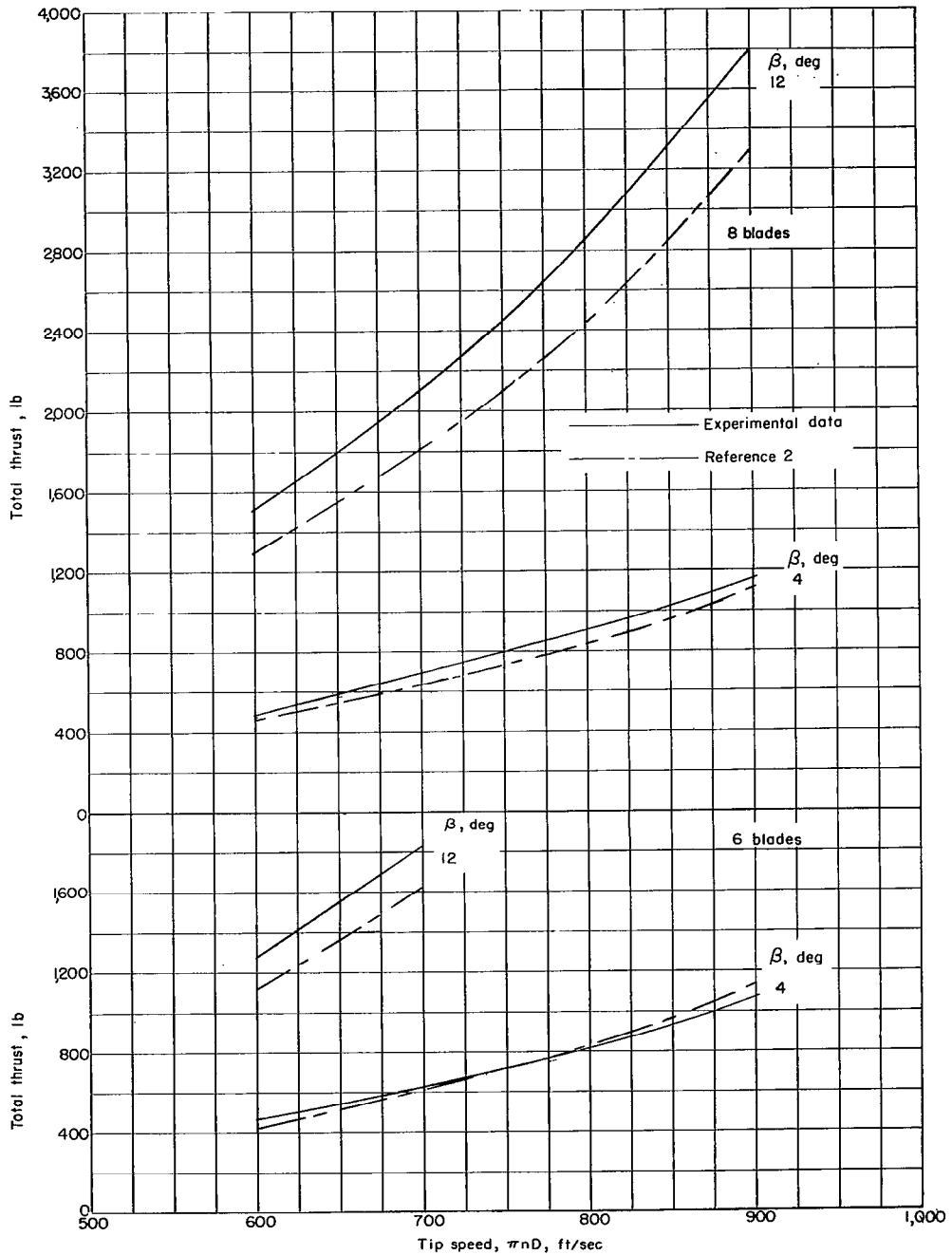


Figure 6.- Comparison of experimental and calculated values of total thrust of NACA 8.75-(5)(05)-037 dual-rotation propeller having six and eight blades.

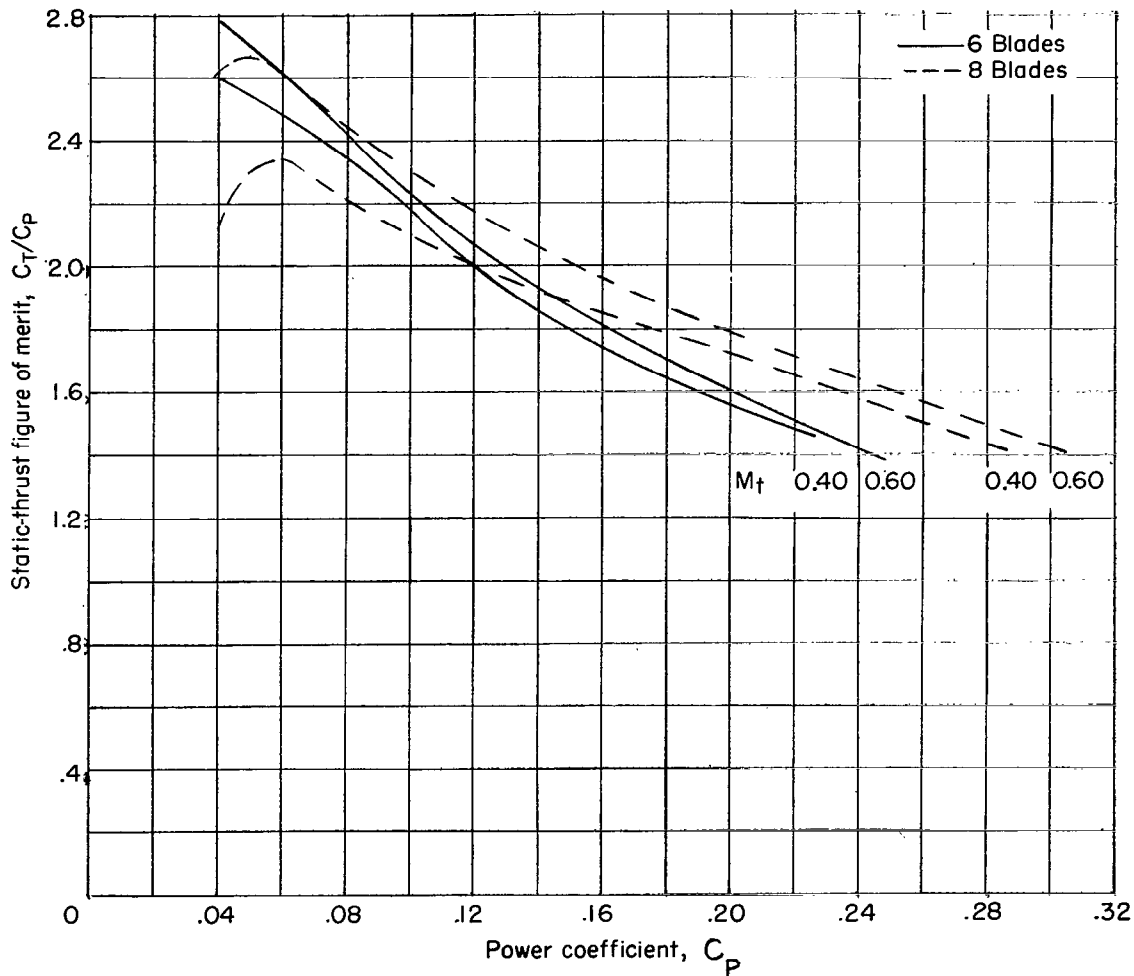
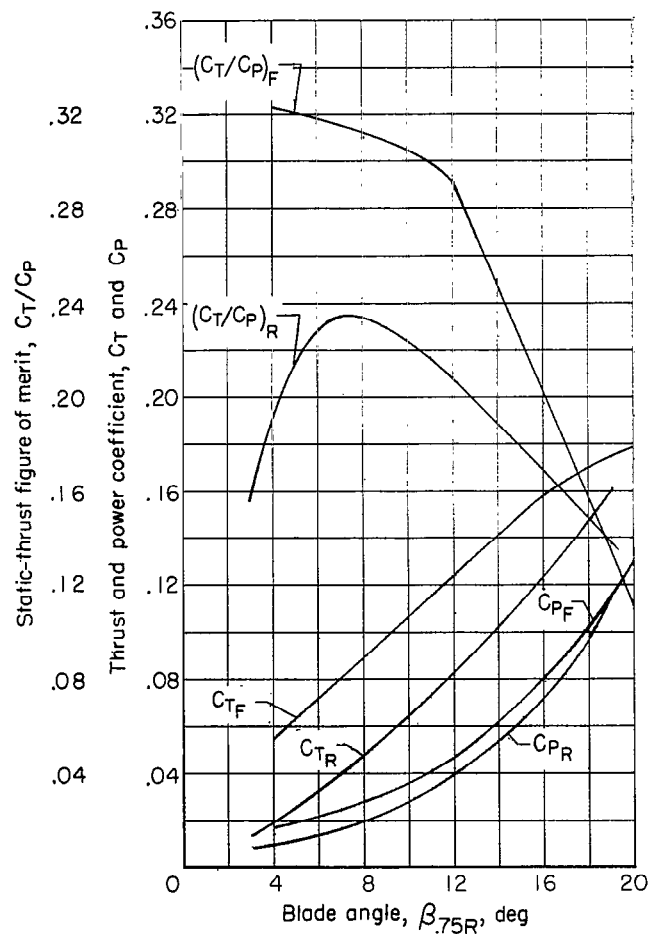
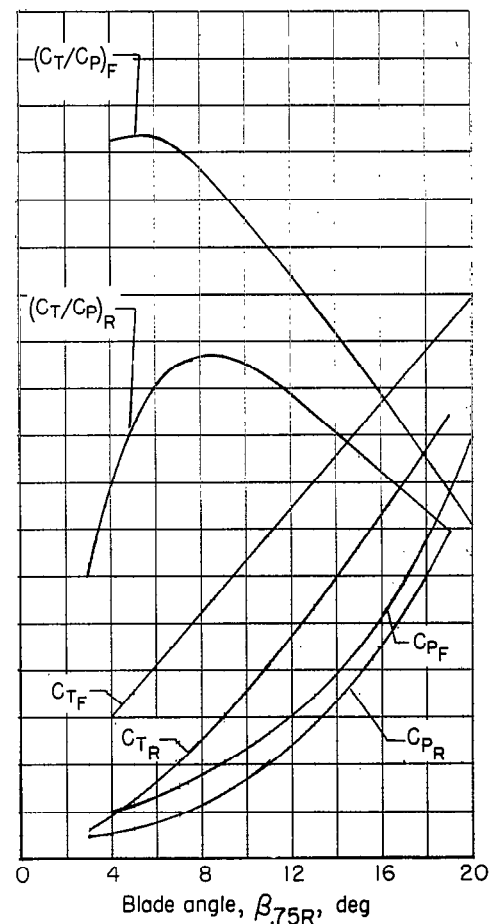


Figure 7.- Variation of static-thrust figure of merit with power coefficient for NACA 8.75-(5)(05)-037 dual-rotation propeller having six and eight blades.



(a) Six blades.



(b) Eight blades.

Figure 8.- Variation of static-thrust coefficient C_T , power coefficient C_P , and static-thrust figure of merit C_T/C_P with blade angle. NACA 8.75-(5)(05)-037 dual-rotation propeller; tip Mach number, 0.60.

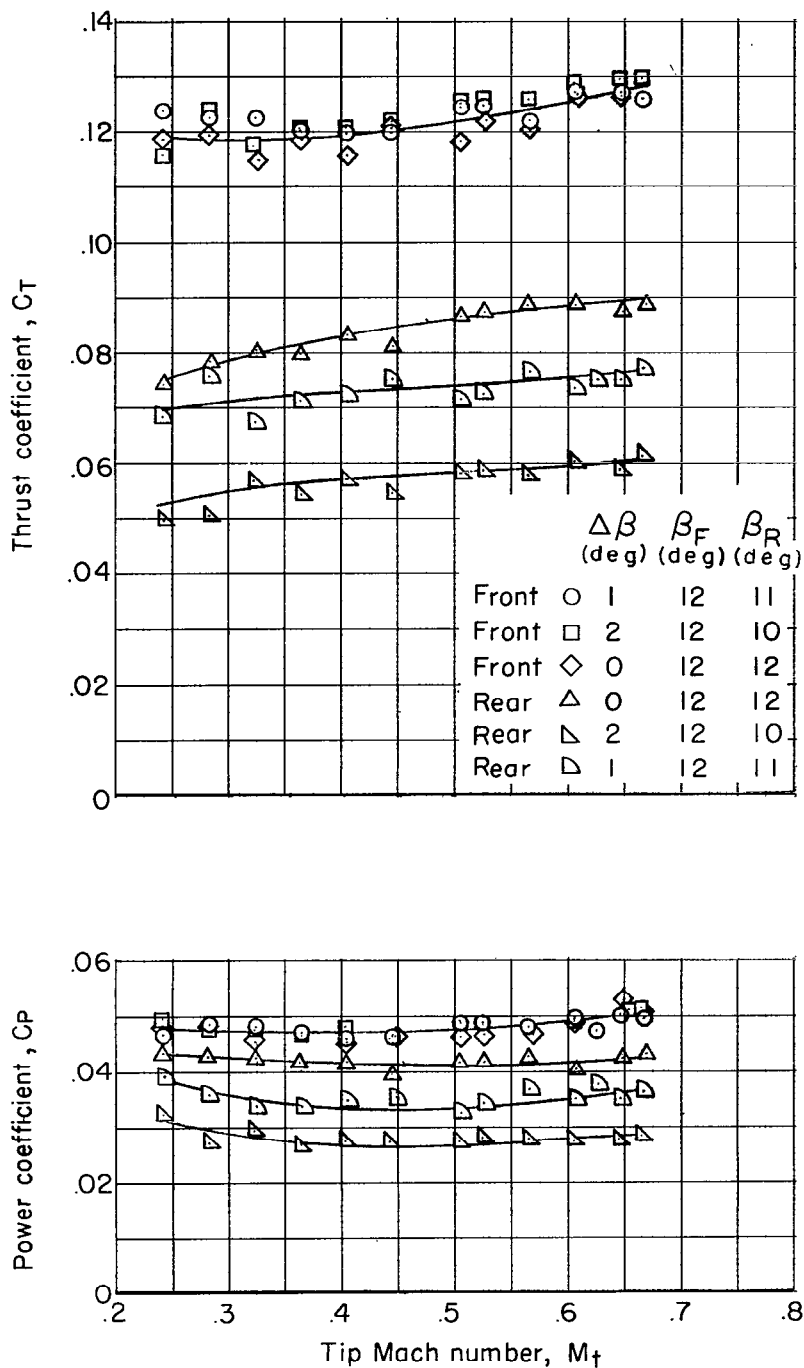


Figure 9.- Variation of C_T and C_P with $\Delta\beta$ and tip Mach number.

NACA 8.75-(5)(05)-037 dual-rotation propeller with six blades.

$\beta_F = 12^\circ$; $\Delta\beta = \beta_F - \beta_R$.



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